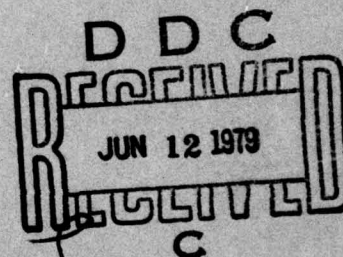AFGL-TR-79-0005
INSTRUMENTATION PAPERS, NO. 274

LEVEL

Satellite Density Measurements With the Rotatable Calibration Accelerometer (ROCA)

FRANK A. MARCOS
K. S. W. CHAMPION

4 January 1979

AERONOMY DIVISION   PROJECT 6690
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731
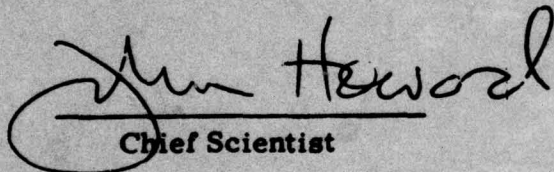
AIR FORCE SYSTEMS COMMAND, USAF

79 06 11 002

This report has been reviewed by the ESD Information Office (OI) and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Chief Scientist

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
AFGL-TR-79-0005	AFGL-IP-274	

4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
SATELLITE DENSITY MEASUREMENTS WITH THE ROTATABLE CALIBRATION ACCELEROMETER (ROCA)	Scientific. Interim.
	6. PERFORMING ORG. REPORT NUMBER
	IP No. 274

7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)
Frank A. Marcos K. S. W. Champion	62101F 66900401

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Air Force Geophysics Laboratory (LKB) Hanscom AFB Massachusetts 01731	62101F 66900401

11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE
Air Force Geophysics Laboratory (LKB) Hanscom AFB Massachusetts 01731	4 January 1979
	13. NUMBER OF PAGES
	22

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Accelerometers
Satellites
Atmospheric density
Aerodynamic drag

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Satellite accelerometer measurements of atmospheric density have provided significant improvement in our understanding of the structure and dynamics of the lower thermosphere. Derivation of accurate data with this technique requires removal of instrument bias from the total sensor output. The ROCA (ROtatable Calibration Accelerometer) experiment was flown to provide an orbital calibration capability on the three-axis stabilized S3-4 satellite. The ROCA sensitive axis could be operated in either of two orientations selectable by ground command. For density measurement (normal

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73

20. Abstract (Continued)

operating mode) the sensitive axis was aligned with the satellite velocity
vector. For direct measurement of bias, the sensitive axis was aligned
perpendicular to the velocity vector. Utilization of the inflight calibration
technique showed a dependence of the bias upon the instrument operating
temperature. Removal of the bias-temperature component from the total
acceleration signal obtained in the normal operating mode permits deriva-
tion of accurate density data. Measurements of atmospheric density were
obtained during approximately 600 orbits over a five month period. The
resulting ROCA data will be utilized for improved satellite ephemeris com-
putations and for detailed studies of the lower thermosphere, particularly
those related to energy inputs at high latitudes.

Contents

Illustrations

6

Satellite Density Measurements With the Rotatable Calibration Accelerometer (ROCA)

1. INTRODUCTION

Atmospheric density measurements have been obtained using the
ROCA (ROtatable Calibration Accelerometer) experiment on the S3-4 satellite.
To accurately determine the atmospheric density the bias must be eliminated
from the total sensor output. On spinning satellites this can be accomplished in
a relatively straightforward manner since the bias is essentially constant and the
density information is modulated at the spacecraft spin rate. On despun satellites
in sufficiently elliptical orbits bias can be determined from the instrument output
at altitudes where the density is negligible. For accelerometer density measure-
ments on low eccentricity despun satellites an alternate technique is required.
An analysis of the bias characteristics exhibited by accelerometers on the Atmos-
phere Explorer satellites showed that ground based values could not be extrapolated
to orbital conditions and that the bias exhibited a temperature dependence.[1] The
ROCA experiment provided a means to measure the bias and its variations in orbit.
This was accomplished successfully in flight by periodically rotating the sensitive
axis perpendicular to the velocity vector. In this configuration the contribution
of air drag (or density) to the total acceleration signal was negligible.

1. Marcos, F.A., and Fioretti, R.W. (1977) Orbital Bias Determination for
    Accelerometers on the Atmosphere Explorer Satellites, AFGL-TR-77-0147.

7

S3-4 was launched into a near polar orbit with perigee and apogee near 165 km and 270 km, respectively. In this low eccentricity orbit an extensive amount of data were obtained in high latitude regions at low satellite altitudes. Considerable new data from the Atmosphere Explorer and S3-1 satellites have become available in the lower thermosphere.[2] However, due to either their inclinations or the perigee precession, about 90 percent of these measurements were at latitudes below 70°. As a result, model improvements using these data are largely limited in latitudinal coverage. The high latitude region is particularly important since it is the source of heating due to ionospheric currents and particle precipitation. Another advantage of the S3-4 orbit is that it permits more accurate examination of the latitudinal characteristics of structural features. Previous low altitude satellites were in considerably more elliptical orbits and measurements made on a specific orbit below 200 km spanned about 30° in latitude. With S3-4, 130° in latitude is spanned below 200 km.

This report describes the orbital performance of the experiment and utilization of the rotation capability in the derivation of accurate atmospheric density data. Typical density profiles are examined and compared to recent atmospheric models. Wave-like structure is observed and appears to be related to localized heating and to propagating waves. Due to data processing difficulties at SAMTEC, Vandenberg, AFB, only a few orbits are presently available. Extensive analyses of the results from this experiment will be described in forthcoming reports.

2. EXPERIMENT DESCRIPTION

2.1 Accelerometer

The ROCA experiment consists of a single axis accelerometer mounted on a rotatable table. The instrument was fabricated by Bell Aerospace Textron.[3] The rotatable base indexes the sensitive axis in either of two positions selectable by ground command. For density measurement, the sensitive axis is aligned with the satellite velocity vector (Position X). For bias determination, the sensitive axis is rotated 90° (Position Y). These modes are represented schematically in Figure 1.

2. Marcos, F.A., McInerney, R.E., and Fioretti, R.W. (1978) Variability of the Lower Thermosphere Determined from Satellite Accelerometer Data, AFGL-TR-78-0134.

3. Lange, W.G. (1977) Accelerometer System for S77-2 Satellite, Final Report, AFGL-TR-77-0179.

SENSOR AXIS

VELOCITY VECTOR

ROCA POSITION X MODE
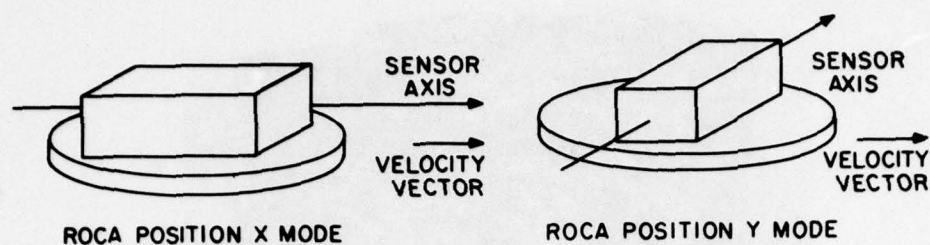
SENSOR AXIS

VELOCITY VECTOR

ROCA POSITION Y MODE

Figure 1. ROCA Flight Orientations

The instrument has two sensitivity ranges, selectable by ground command, for orbital acceleration measurements. Ranges A and B had sensitivities of approximately 8×10^{-3} g full scale and 1×10^{-3} g full scale respectively. Full scale corresponded to an output frequency of 8.8 Khz. Table 1 gives values of scale factor, bias and their temperature dependence as determined from ground calibration. Range B was used for air drag measurement throughout the flight. In this mode, Range A automatically came on for the first 25 sec after power turn-on was applied. This feature was incorporated to provide sufficient force to initially suspend the proof mass. The cross-axes suspension scaling associated with Ranges A and B was 1 g and 10^{-3} g, respectively. Sample time of the instrument was one-quarter second. Maximum power consumption was 6.5 watts. Figure 2 shows the assembled ROCA experiment. The complete experiment assembly has the dimensions 6.4 in. high, 6 in. wide and 9 in. long and a weight of 11.0 pounds.

Table 1. Ground Calibration for ROCA Scale Factor and Null Bias

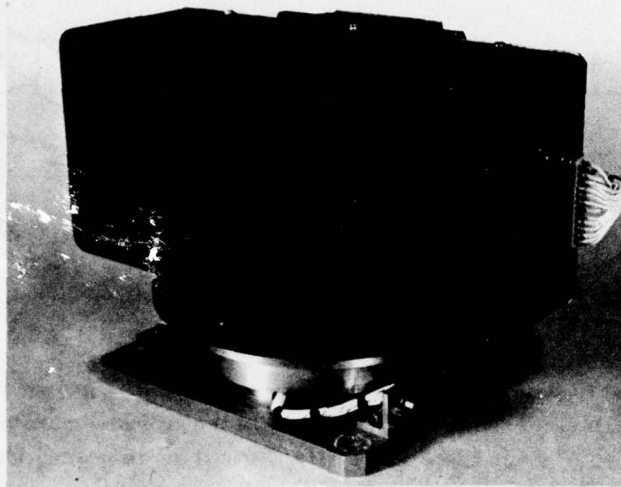|	Scale Factor		Null Bias	
Temp.	Range A	Range B	Range A	Range B*
30°F	1.0622 pps/μg	8.525 pps/μg	+20.4 μg	+0.051 μg
70°	1.1002	8.824	+30.8	+0.077
120°	1.1541	9.251	+36.4	+0.091

*Extrapolated from Range A data.

9

Figure 2. ROCA Flight Hardware

Rotation of the base is accomplished with a reversing dc motor and gear train. The contractor selected a dc motor which was available within the required delivery time. The motor was modified to operate in a hard vacuum environment by the use of special lubricants and brush material. The manufacturer, Clifton Precision Division of Litton Industries, stated that this would ensure reliable space operation for at least 200 hr. This would allow a nominal 24,000 X to Y position operations. Upon receipt of a position command 28 volts dc is applied to the motor. This causes it to rotate until it reaches its new position 90° from the previous one. Limit switches interrupt the power after the base has been driven against a spring loaded mechanical stop. Receipt of another position command energizes a relay which reverses the 28 volt polarity. The motor then rotates the base back to its original position. Problems were encountered in preflight tests of this motor. During thermal vacuum tests at the spacecraft integration facility, an increase in the rotation time from a nominal 30 sec to over 70 sec was observed. During electromagnetic interference tests at the spacecraft integration facility noise spikes exceeding specifications were encountered. These had not occurred in pre-delivery tests. The problem was identified as the hard brush creating debris and excessive wear of the commutator segments. Selection of a replacement motor was not feasible because of the launch schedule. Bell Aerospace Textron estimated a useful life of only about 10 hr. of operation. It was possible to circumvent this problem by a revision in the flight operation plan. This revision is discussed in the next section.

10

2.2 Flight Summary

The S3-4 satellite was launched during March 1978 into a 98° inclination orbit. The initial perigee and apogee heights were 165 km and 270 km respectively. Latitude of perigee was 30°N and perigee local time was 1130 hr. An orbit-adjust propulsion system was used to maintain orbit for a 6 month period. Routine data taking scheduled for S3-4 experiments consisted of a 20-day cycle of 17 days with either full orbit (90 min) passes or half orbit (45 min) passes depending on whether a high data rate mode was selected for one of the other experiments, and three days with 20 min of data centered near perigee collected each orbit. It was initially planned to rotate the instrument from Position X to Position Y twice each day, near apogee, and to collect one full data orbit per week in Position Y to obtain calibration data. Evaluation of the potential for motor malfunction caused revision of the calibration procedure. Data were scheduled for acquisition in Position X only for the first month of flight. Subsequent to this period the calibration procedure consisted of one full day in Position Y each week. The instrument was turned on during March 1978. Instrument operation was normal for the next five months. In August 1978, during orbit 2472, the instrument power fuse blew following a rotation command. The most probable cause of failure appears to be a short circuit in the motor. The most likely cause of motor failure was excessive brush wear and/or buildup of brush material debris which shorted the 28 volt input power line. During its 5 months of operation, ROCA acquired over 600 orbits of valuable information concerning atmospheric density and its variations.

3. RESULTS

Data obtained in the bias calibration mode (Position Y) during orbit 1348 are shown in Figure 3. The top curve (Figure 3a) gives the acceleration output, in units of micro-g's, vs. GMT. If the bias were constant, a constant output would be expected (neglecting short term variations due to instrument or spacecraft noise). The data show an average bias of about 37 μg with a linear decrease from 38 μg to 36.5 μg. The measured bias average value is about 700 times higher than the essentially negligible value shown in Table 1. The change in bias appears to be a bias temperature effect similar to that observed in the Atmosphere Explorer (AE) accelerometer data. Figure 3b shows a linear increase of 11°F in the instrument operating temperature. A bias temperature coefficient $T_c = 0.14$ μg/^{O}F is derived for this orbit. This value is about 300 times larger than the prelaunch data given in Table 1, but of the order of the orbitally determined values of T_c for the AE accelerometers. The large values of bias and bias-temperature coefficient are

11

ROCA CALIBRATION DATA
ORBIT 1348   DAY 78158

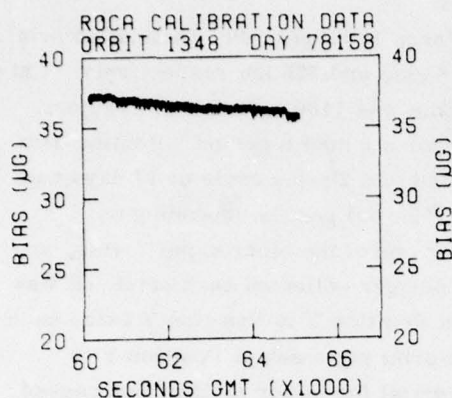ROCA TEMPERATURE DATA
ORBIT 1348   DAY 78158

Figure 3a.   Measured Orbital Accel-
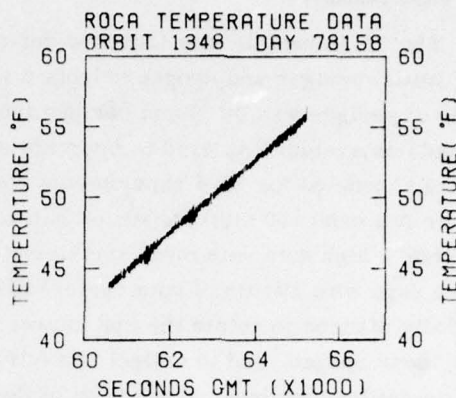erations in Calibration Mode vs GMT
for Orbit 1348

Figure 3b.   ROCA Temperature vs
GMT for Orbit 1348

similar to those derived for Range A data, although the instrument was in Range B throughout the flight, except for the first 25 sec of each turn on.   There is no possibility that the instrument remained in Range A.   The instrument manufacturer believes that the Range A bias calibration data are reasonably accurate but that the bias does not scale down with the suspension voltage.   Hence, their extrapolation of the data to obtain Range B bias values are incorrect.   The scale factor values for both ranges are believed to be extremely accurate.[4]   It can be concluded that although the orbital bias characteristics differed significantly from the ground-based values, the ROCA provided a successful inflight measurement which can be used for inflight calibration.   The output of the ROCA in the Y-mode (a_y) can be represented by:

$$a_y = B(1 + T_c) + N_y \tag{1}$$

where N_y represents both vehicle-induced accelerations sensed along the Y-axis and internal instrument noise.

Figure 4 shows data for orbit 1351 with ROCA in the Position X mode.   Figure 4a shows measured acceleration values vs time.   Apogee and perigee values are also indicated.   The data show a characteristic drag profile with maximum drag accelerations occurring near perigee.   The first apogee value is about 1.5 μg higher than the second, consistent with the data of Figure 3.   Figure 4b again shows

---

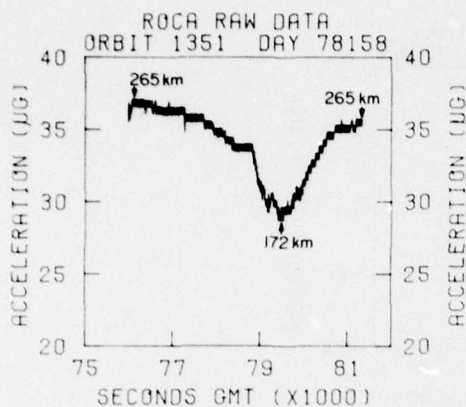4.   Lange, W.G. (1978) Private Communication.

12

ROCA RAW DATA
ORBIT 1351   DAY 78158

265 km
265 km
172 km

ACCELERATION (µG)
SECONDS GMT (X1000)

ROCA TEMPERATURE DATA
ORBIT 1351   DAY 78158

TEMPERATURE (°F)
SECONDS GMT (X1000)

Figure 4a.   Measured Orbital Accel-
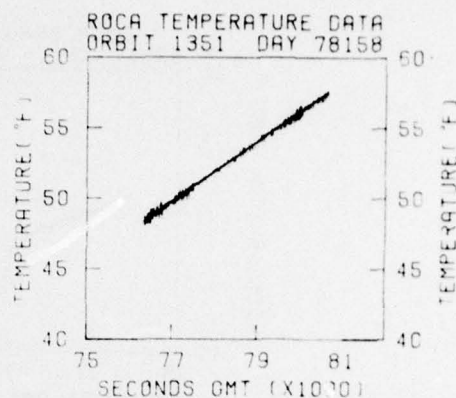erations in Density Mode vs GMT for
Orbit 1351

Figure 4b.   ROCA Temperature vs
GMT for Orbit 1351

an 11°F instrument temperature rise during this orbit.   For Position X data the
total acceleration output (a_x) can be represented by:

$$a_x = a_D + B(1 + T_c) + N_x \tag{2}$$

where a_D is drag acceleration and N_x represents both vehicle induced accelerations
sensed along the x-axis and internal instrument noise.

In the derivation of atmospheric density values from measured drag accelera-
tions obtained in the X-mode, the accelerations due to instrument and vehicle noise
are largely removed using numerical filtering techniques.[5]   Drag is determined
from Eqs. (1) and (2):

$$a_x - a_y = a_D \tag{3}$$

Figure 5 shows the drag profile derived from orbit 1351 using the calibration data
from orbit 1348.   The maximum deflection due to drag is 7 µg.   Atmospheric den-
sity (ρ) is calculated from the drag, using the classical expression[6]:

$$\rho = \frac{2Ma_D}{C_D A V^2} \tag{4}$$

5. Noonan, J.P., Fioretti, R.W., and Hass, B. (1975) Digital Filtering Analysis
      Applied to the Atmosphere Explorer-C Satellite MESA Accelerometer Data,
      AFGL-TR-75-0295.

6. King-Hele, D. (1964) Theory of Satellite Orbits in an Atmosphere,
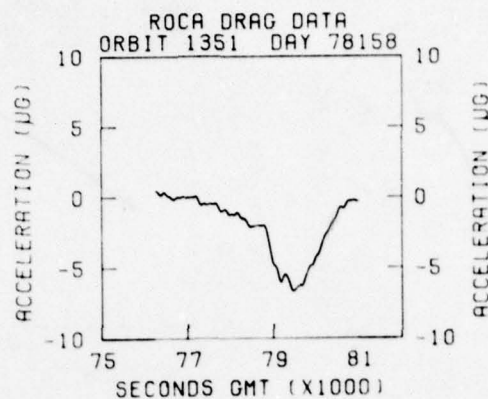   Butterworth and Co., London.

13

ROCA DRAG DATA
ORBIT 1351   DAY 78158

Figure 5. Aerodynamic Drag Profile for
Orbit 1351 Using Inflight Calibration Data

where C_D, A, M and V are the satellite's drag coefficient, cross-sectional area, mass and velocity respectively. Assuming a value of $M/C_DA = 41.7 \text{ cm}^2/\text{gm}$ the density profile of Figure 6 was derived. Downleg and upleg data are indicated by circles and crosses, respectively. Perigee values of altitude, geographic coordinates and time are shown in the upper right hand corner of the figure. Geographic latitude is also noted at selected points. Density values from the Jacchia 1971[7] models are shown as solid lines terminated by either a triangle (downleg data) or an asterisk (upleg data). The measured data, taken during a period when $K_p = 3$ reveal highly structured features not incorporated into the models. Horizontal wavelengths of about 400 km are observed for the peaks at 210 and 230 km. Wavelengths of this order at low satellite altitudes have been previously detected, for example, by accelerometers on the OV1-15 satellite.[8] These features were related to enhancements in the auroral electrojet.[9]

The advantages of the S3-4 orbital characteristics and the accelerometer accuracy for the elucidation of high latitude heating processes are demonstrated in Figure 7. This plot examines the orbit 1351 density data in relation to the

7. Jacchia, L.G. (1971) Revised Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles, Spec. Rept. 332, Smithsonian Astrophysical Observatory, Cambridge, MA.

8. Marcos, F.A., and Champion, K.S.W. (1972) Gravity waves observed in high latitude neutral density profiles, Space Res. 12:791.

9. Forbes, J.M., and Marcos, F.A. (1973) Thermospheric density variations associated with auroral electrojet activity. J. Geophys. Res. 78:3841.
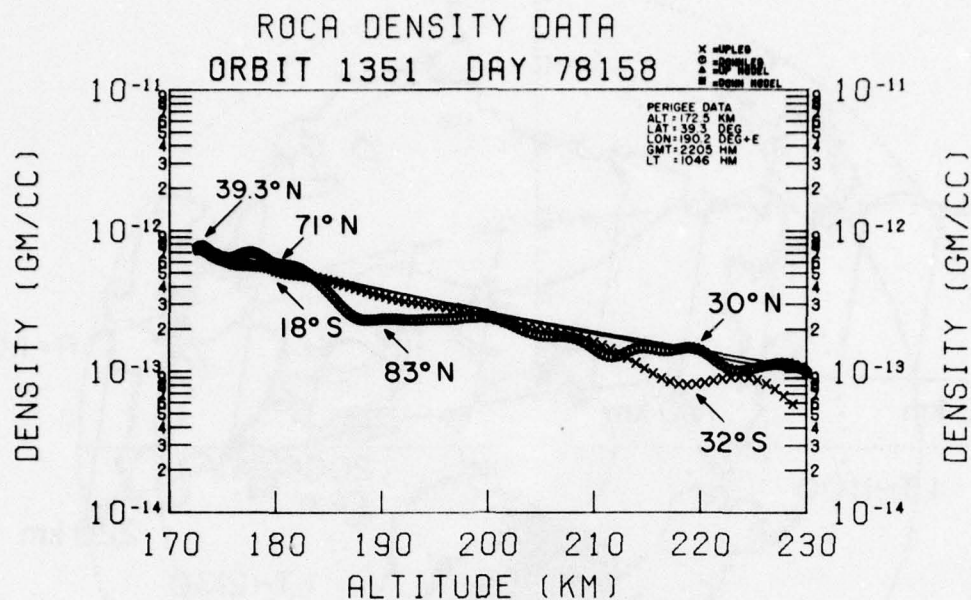
Figure 6. Atmospheric Density Profile and Model Values as a Function of Altitude for Orbit 1351

Northern auroral zone. The ratio of measured density to the model is given on a polar coordinate plot between 90°N and 40°N. The orbit trajectory (solid line terminated by an arrow) crosses the nightside auroral zone between 65 and 70°N and the dayside auroral zone between 81 and 83°N. The auroral zone boundaries are determined using the data of Whalen.[10] The orbit permits near simultaneous measurement in the nightside and dayside auroral zones at altitudes below 200 km. Also, the region of the dayside auroral zone traversed by the satellite corresponds to the cusp region. Recent evidence has indicated that particle precipitation is centered near magnetic noon at latitudes that are essentially the same as the daytime part of the auroral oval.[11] The northern hemisphere density profile shows a 10 percent enhancement between 204.2 km and 201.3 km followed by a maximum decrease of about 25 percent near the pole and subsequent increase in

10. Whalen, J.A. (1970) Auroral Oval Plotter and Nomograph for Determining Corrected Geomagnetic Local Time, Latitude and Longitude for High Latitudes in the Northern Hemisphere, AFCRL-70-0422.

11. Heikkila, W.J., Winningham, J.D., Eather, R.H., and Akasofu, S.I. (1972) Auroral emissions and particle precipitation in the noon sector, J. Geophys. Res. 77:4100.
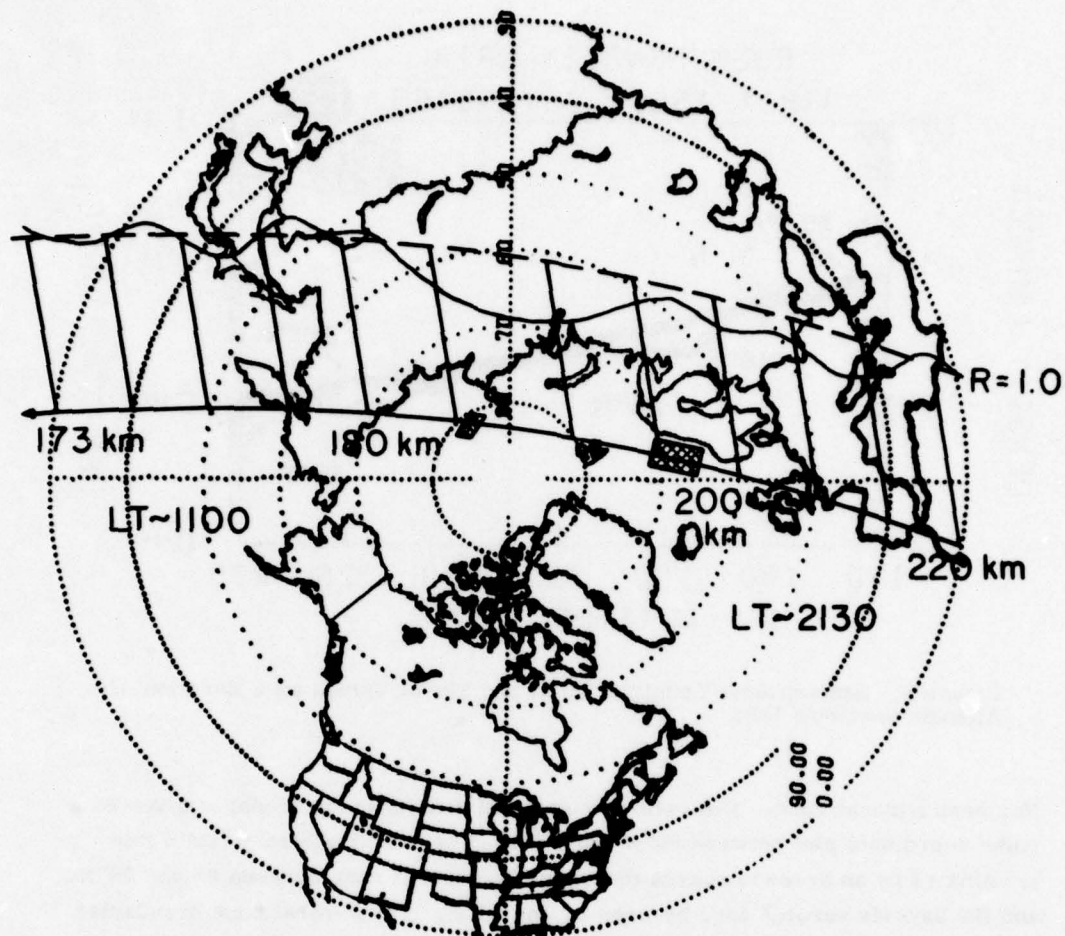
15

Figure 7. Geographic Location of Orbit 1351 Data in Relation to Northern
Hemisphere Auroral Zone

density on the dayside of the orbit beginning near the auroral zone. Although not
shown on this plot, the orbit also passes through the southern hemisphere night-
time auroral zone near apogee. Hence, considerable new understanding of high
latitude heating is anticipated. In addition to the advantageous orbital character-
istics, analysis of the ROCA data may be enhanced by correlation with comple-
mentary S3-4 measurements of the auroral zone as determined by CRL-246
Vacuum Ultraviolet Background measurements. These radiation measurements
were obtained with a spectrometer and photometer under the direction of

Dr. R. E. Huffman, AFGL.[12] Photographs of the visible aurora obtained from the DMSP satellite are also available. Utilization of these data will permit correlation of density features with the actual, rather than statistically determined, auroral region.

Figures 8a-c show density profiles determined from three orbits earlier in the flight. These plots are shown to demonstrate typical results obtained to date. The orbit 374 and 383 data show fairly little structure while the orbit 255 data show a marked density decrease at 175 km downleg similar to that observed during orbit 1351.

There appear to have been few other measurements of the neutral atmosphere with the simultaneous low altitude and near pole-to-pole latitude coverage of S3-4. The LOGACS accelerometer experiment obtained continuous data for a period of about four days. These measurements covered a severe geomagnetic disturbance, however, and provided considerable insight into atmospheric processes.[13] Results from 90 orbits of neutral density measurements over a two month period made with an ionization gauge on the 1972-32A satellite have been reported.[14] Also, six days of accelerometer measurements obtained at the single altitude of 143 km with the 1970-48A satellite have been analyzed.[15] The successful ROCA flight with 600 orbits of data gathered over a five month period provides a unique opportunity to study the heating, structure and dynamics of the lower thermosphere.

12. Huffman, R.E. (1978) AFGL, Private Communication.

13. Devries, L.L. (1971) Experimental Evidence in Support of Joule Heating Associated with Geomagnetic Activity, Marshall Space Flight Center, NASA TMX-64568.

14. Ching, B.K., Palmer, J., and Carter, V.L. (1974) Upper Atmospheric Density Inferred from Magnetron Data from the Satellite 1972-32A, Aerospace Corp. Report No. TR-0074(4260-10)-7.

15. Rugge, H.R., and Ching, B.K. (1975) Atmospheric density from the low altitude satellite 1970-48A: comparison of orbital decay measurements, Accelerometer Measurements and Atmospheric Models, Planet. Space Sci. 23:323.
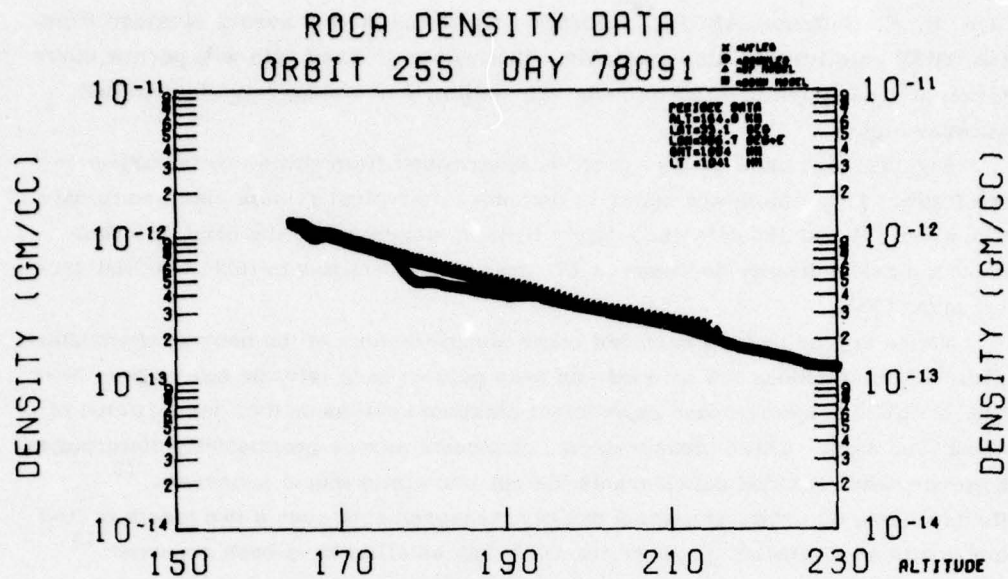
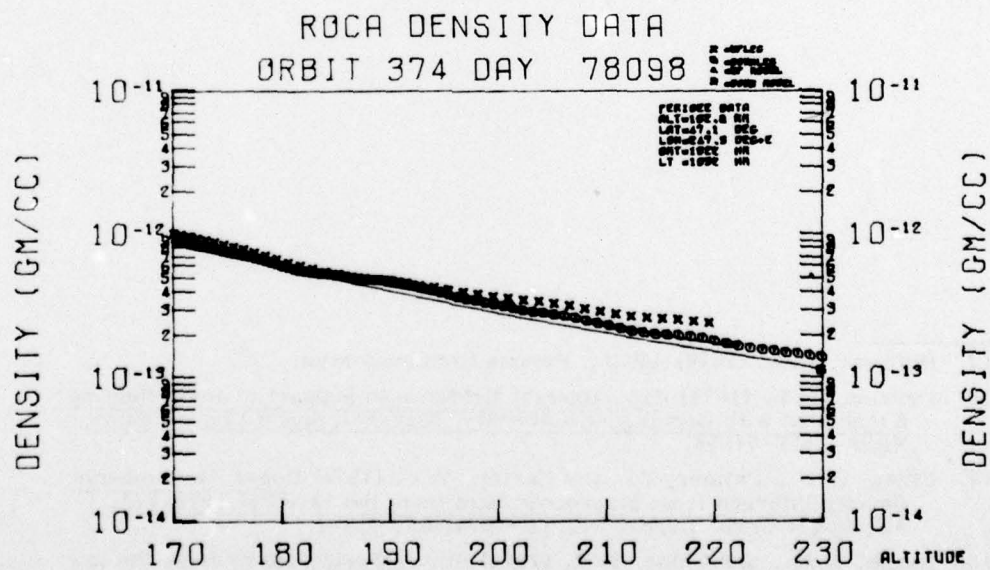Figure 8a. Atmospheric Density Profile and Model Values for Orbit 255

Figure 8b. Atmospheric Density Profile and Model Values for Orbit 374
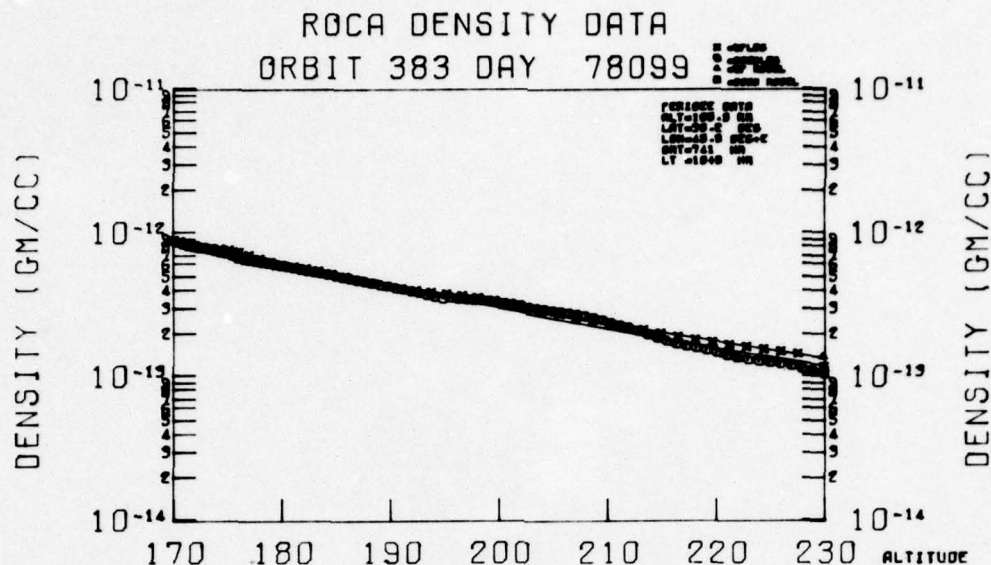
18

ROCA DENSITY DATA
ORBIT 383 DAY   78099

Figure 8c.   Atmospheric Density Profile and Model Values for Orbit 383

4. CONCLUSIONS

An analysis of the orbital performance of the ROCA experiment reveals the following:

(a) The instrument rotation capability was successfully used for orbital calibration of bias.

(b) The average bias and bias temperature coefficient determined inflight were over two orders of magnitude higher than the values deduced by ground calibration.

(c) Utilization of the inflight measurements of bias characteristics permits accurate density measurements.

(d) The 600 orbits of data gathered during a five month period provide a significant increase in the amount of data available for analysis in this region of the thermosphere.

(e) The S3-4 orbital characteristics permit routine monitoring of the auroral zone. This, coupled with the high accuracy density measurements and the capability to correlate with the CRL-246 on-board measurements permits a unique opportunity to study high latitude heating, structure and dynamics.

Results detailing the geophysical significance of the ROCA experiment will be described in forthcoming papers.

19

References

1. Marcos, F.A., and Fioretti, R.W. (1977) Orbital Bias Determination for Accelerometers on the Atmosphere Explorer Satellites, AFGL-TR-77-0147.

2. Marcos, F.A., McInerney, R.E., and Fioretti, R.W. (1978) Variability of the Lower Thermosphere Determined from Satellite Accelerometer Data, AFGL-TR-78-0134.

3. Lange, W.G. (1977) Accelerometer System for S77-2 Satellite, Final Report, AFGL-TR-77-0179.

4. Lange, W.G. (1978) Private Communication.

5. Noonan, J.P., Fioretti, R.W., and Hass, B. (1975) Digital Filtering Analysis Applied to the Atmosphere Explorer-C Satellite MESA Accelerometer Data, AFGL-TR-75-0295.

6. King-Hele, D. (1964) Theory of Satellite Orbits in an Atmosphere, Butterworth and Co., London.

7. Jacchia, L.G. (1971) Revised Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles, Spec. Rept. 332, Smithsonian Astrophysical Observatory, Cambridge, MA.

8. Marcos, F.A., and Champion, K.S.W. (1972) Gravity waves observed in high latitude neutral density profiles, Space Res. 12:791.

9. Forbes, J.M., and Marcos, F.A. (1973) Thermospheric density variations associated with auroral electrojet activity, J. Geophys. Res. 78:3841.

10. Whalen, J.A. (1970) Auroral Oval Plotter and Nomograph for Determining Corrected Geomagnetic Local Time, Latitude and Longitude for High Latitudes in the Northern Hemisphere, AFCRL-70-0422.

11. Heikkila, W.J., Winningham, J.D., Eather, R.H., and Akasofu, S.I. (1972) Auroral emissions and particle precipitation in the noon sector, J. Geophys. Res. 77:4100.

12. Huffman, R.E. (1978) AFGL, Private Communication.

13. Devries, L.L. (1971) Experimental Evidence in Support of Joule Heating Associated with Geomagnetic Activity, Marshall Space Flight Center, NASA TMX-64568.

21

14. Ching, B. K., Palmer, J., and Carter, V. L. (1974) Upper Atmospheric Density Inferred from Magnetron Data from the Satellite 1972-32A, Aerospace Corp. Report No. TR-0074(4260-10)-7.

15. Rugge, H. R., and Ching, B. K. (1975) Atmospheric density from the low altitude satellite 1970-48A: comparison of orbital decay measurements, Accelerometer Measurements and Atmospheric Models, Planet. Space Sci. 23:323.